FLSD as a good choice in sheet forming of AHSS

R. Hernández, A. Llobet, X. Gomez and M.D. Riera

Fundació CTM Centre Tecnològic http://www.ctm.com.es

Avda. Bases de Manresa, 1. 08242-MANRESA (Barcelona)

Abstract: The automotive industry has increased significantly the use of advanced high strength steels (AHSS) in many structural components, with the aim to reduce weight and also to increase safety. The high resistance of these steels is accompanied by a decrease in formability, which makes simulation a requirement to adequately foresee the formability of a particular stretch formed component. This work shows that Abaqus can be used in the cold stamping calculations, by mainly estimating the occurrence of rupture and necking during forming. Formability studies usually use forming limit diagrams (FLD), based on stains, as a failure criterion, but this approach is not effective when working with AHSS. This work proposes the use a forming limit stress Diagram (FLSD) based on the main stresses acting on the material. A brief explanation of how to obtain these FLSD curves is presented, where ABAQUS also plays an important role. Finally, comparisons using simulations from AUTOFORM and real parts are shown and discussed. The comparison was performed using Abaqus CAE and Viewer as post-processing tools. A script allows reproducing the mesh generated by AUTOFORM, map the data and post-process with the FLSD criterion. All the methodology presented uses ABAQUS as an integral tool, from the characterization of the material to the analysis of complex parts.

Keywords: AHSS, FLSD, Cold Stamping, Formability.

1. Introduction

The excellent combination of strength and ductility of advanced high strength steels (AHSS) has made them excellent candidates for the manufacture of structural parts in the automotive industry, enabling the production of lightweight components with improved vehicle safety. However, widespread use in sheet metal forming processes is limited by 3 major problems:

a) Difficulties in the evaluation of material formability and manufacturability of parts. Conventionally stamping simulations use the forming limit curve (FLC) as main failure criterion [1]. These are effective in conventional steel forming, but when applied to AHSS prediction is not always correct. Moreover, there exist an uncertainty about the validity of the FLC, because significant differences have been found between FLCs made in different laboratories, even when similar experimental methods have been used. These steels exhibit a higher sensitivity to strain path, and for this reason it is difficult to use a failure criterion based on strains [2].

b) Problems in predicting the final shape of formed pieces. The great strength of these steels is also accompanied by a large springback, which creates large differences between die geometry and final shape [3]. The common solution is to use a simulation analysis as a guide to compensate for sprinback, but inevitably the process ends with a traditional craftsman adjusting the forming tools.

c) Forming tools are subjected to high contact pressures. The wear and fracture generated in dies and punches increases maintenance cost [4-5]. New tool steels with excellent properties and hard coatings have been developed and are an excellent choice when forming AHSS. However, fewer parts before tool failure can be produced, when compared to parts formed using conventional steels.

This work focuses on the first problem described. It discusses the difficulties associated with the FLC criterion and the forming limit stress diagram (FLSD) is proposed as an alternative approach. A procedure to generate de FLSD is shown, where simulation plays a key role. In addition the mechanical behavior of different steels is described in order to obtain FLSD.

2. Materials Characterization

Three AHSS included in the family of dual phase (DP) steels were studied, namely DP780, DOCOL1200 and DOCOL1500 with thickness of 1.6mm.

2.1 Stress-Strain Curve

The sheet metal is subjected to triaxial stresses during drawing, which can reach strains above localized necking . Information obtained from a conventional tensile test is not sufficient to determine the level of strain hardening at higher deformations. Extrapolations are needed to describe the stress-strain relationship until saturation.

Higher levels of uniform strain without necking were achieved by performing a compression test on a stack of metal sheet disks (Figure 1). The absolute value of the tensile and compression behaviors were assumed equal which allows selecting a hardening model of less uncertainty. Figure 2 shows the compression test results.

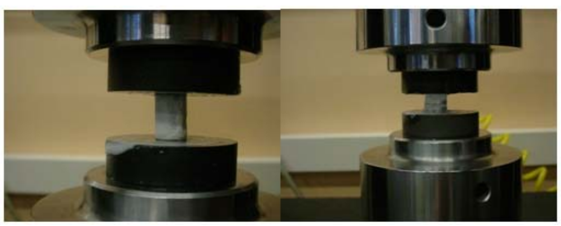

Figure 1. Compression test

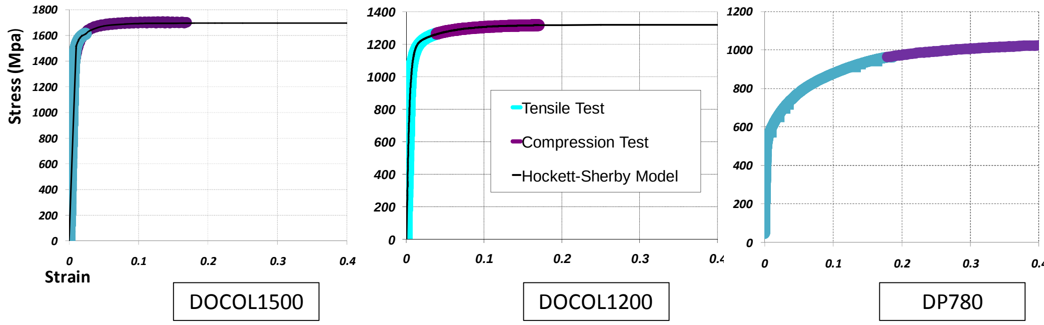

Figure 2. Curves σ-e (tensile, compression and model)

The Hollomon model fits best the DP780 curve, but for higher steels grades the Hockett-Sherby model was used with an additional parameter to produce a best fit. Based on these models it was possible to fully extrapolate the stress-strain curve.

2.2 FLC plots

The FLD determination was made in the CTM laboratories using the NAKAZIMA testing procedure. These tests consist in drawing a semispherical tool to impose a linear strain path on sheet metal blanks, and measure the minimum and maximum strains close to fracture zone of each specimen. Figure 3 shows the tool geometry of NAKAZIMA test (punch and die), the experimental device used, and two specimens tested. The Figure 4 shows the results of the FLD diagram for DP780, DOCOL1200 and DOCOL1500 steels.

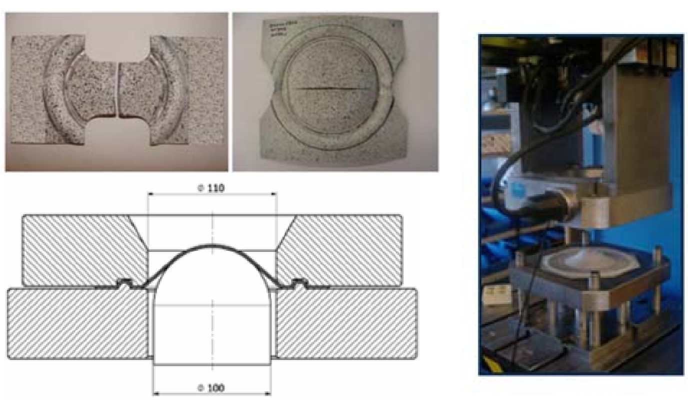

Figure 3. Setup to generate the FLD.

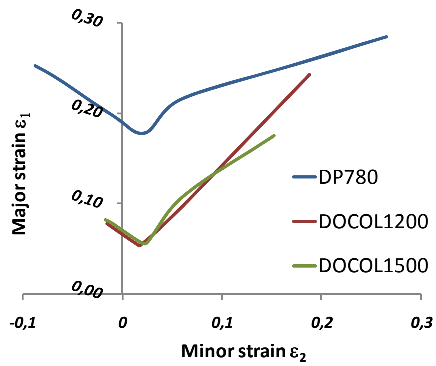

Figure 4. FLD by NAKAZIMA test for DP780, DOCOL1200 y DOCOL1500**.**

The FLSD is obtained by plotting the values of minimum and maximum main stresses at the most critical areas close to fracture. Today there is no direct experimental method to determine the stresses inside the material. In this case the simulation plays a fundamental role, because it indirectly allows obtaining the stress state on the deformed piece.

Reproduction of strain paths and failure of different specimens was possible through the simulation of NAKAZIMA test and the FLD criterion obtained in the laboratory. The simulations allowed determining the states of maximum and minimum stresses in the plane of the blank before the fracture. In Figure 5 the NAKAZIMA test model is shown as simulated by Abaqus. Also in Figure 5 the results for a specimen are shown for the moment when the deformation of the central zone of the sheet has exceeded the FLD criterion (FLDCRT = 1). In this example the damage evolution was enabled and the elimination of the elements took place when FLDCRT = 1.

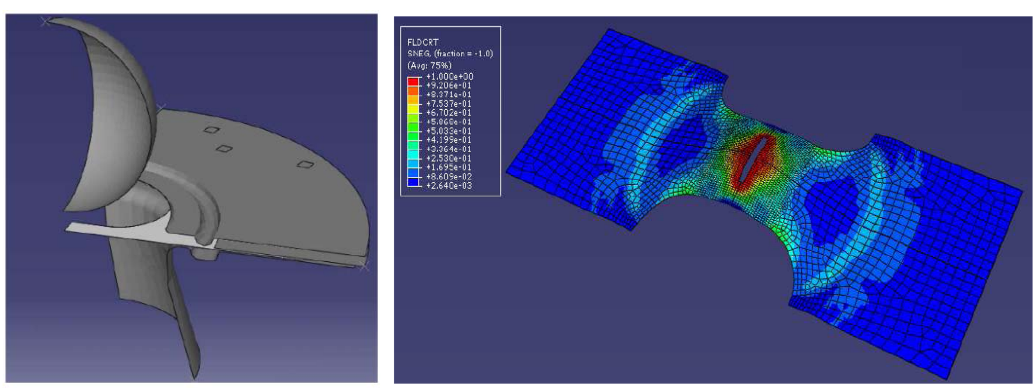

Figure 5. NAKAZIMA test modeled in Abaqus and results of formed specimen

The values of maximum and minimum main stresses of the areas near the fracture were used to plot a cloud of points that outline the border of allowable stresses. This boundary line is the FLSD for each material under study. In Figure 6 the FLSDs for DP780, DOCOL1200 and DOCOL1500 steels are shown.

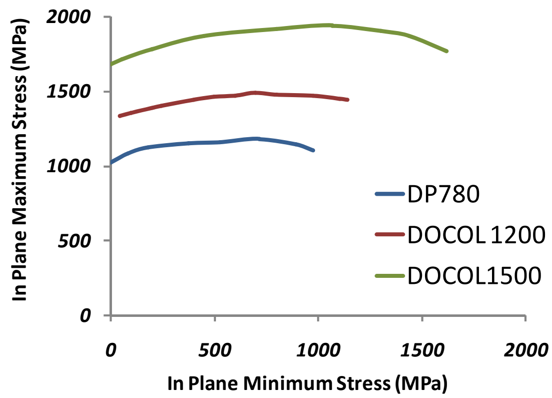

Figure 6. FLSD of DP780, DOCOL1200 and DOCOL1500

3. Forming simulation

In order to validate the FLSD criterion an specimen was designed. Its geometry is shown in Figure 7. Its main feature is an important change in section that introduces a nonlinear deformation path. Figure 8 to 10 show the simulation results when the FLSD criterion indicates failure (FLSDCRT=1) for the different materials under study.

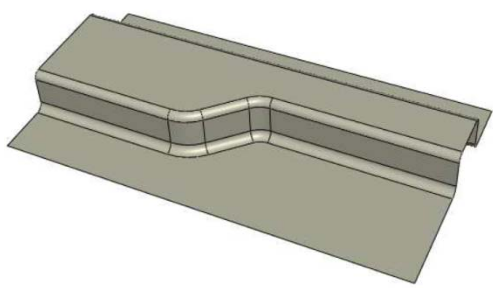

Figure 7. Geometry of the designed specimen.

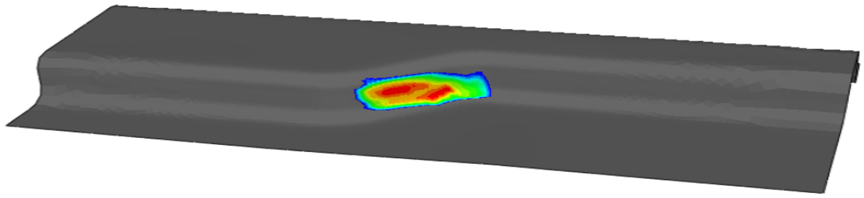

Figure 8. Instant when FLSDCRT=1 for DP780. (Drawing depth 20mm)

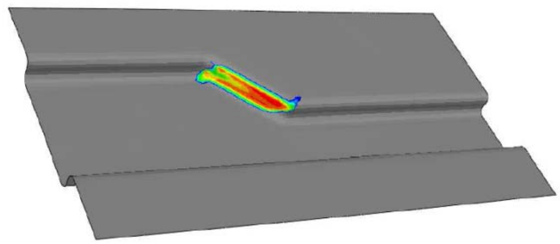

Figure 9. Instant when FLSDCRT=1 for DP1200. (Drawing depth 11mm)

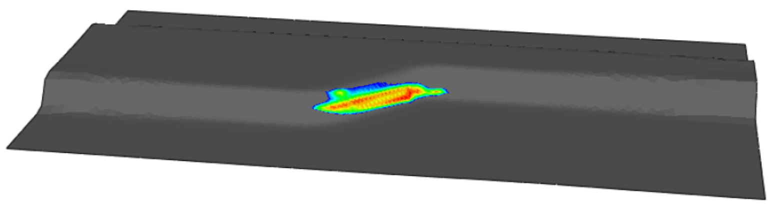

Figure 10. Instant when FLSDCRT=1 for DP1500. (Drawing depth 10mm)

These same models have been solved with AUTOFORM. A Python script using Abaqus/CAE APIs postprocesses the AUTOFORM results to obtain the estimated FLSDCRT. The workflow for the script is shown in Figure 11.

The scrip reads the AUTOFORM output files, and creates an inp file that contains the AUTOFORM mesh for the simulated part. This inp file is imported into the CAE using the function *mdb.ModelFromInputFile()*. A mechanical model based on this mesh is created and a job is submitted. The resulting odb output file contains only the mesh and a COORD fieldoutput. Then the script creates new fieldoutputs that contain the results for strains and stresses from AUTOFORM. Finally the failure criteria results are included as fieldoutputs. The FLSD criterion values are calculated reading the results for maximum and minimum stress in the middle section of the shell corresponding to each element. This pair of stresses produce a value in the FLSD diagram. This values are then added as a fieldoutput.

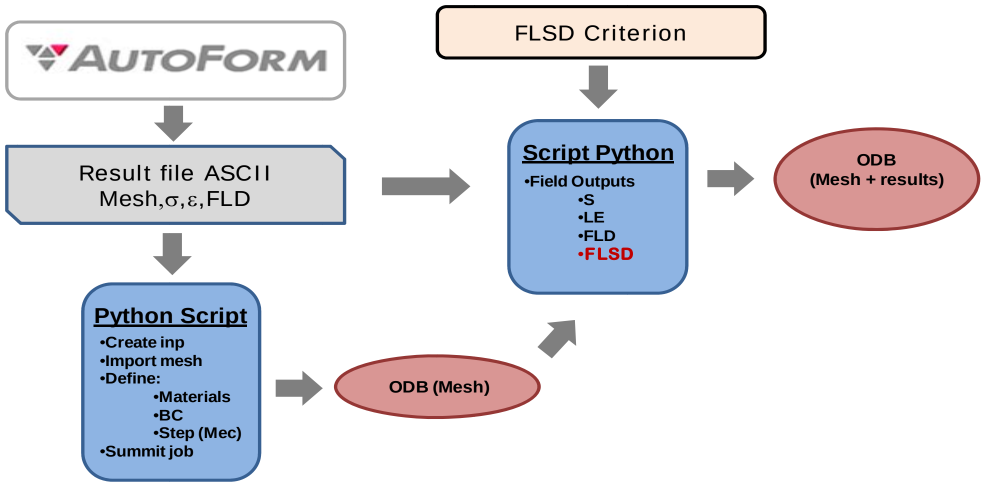

Figure 11. Workflow for the script that creates an odb based on AUTOFORM results.

At the end of the postprocessing the user has an Abaqus odb file that can be opened with Abaqus/Cae, Abaqus/Viewer or any other postprocessing software able to read odb files. An example result is shown in Figure 12.

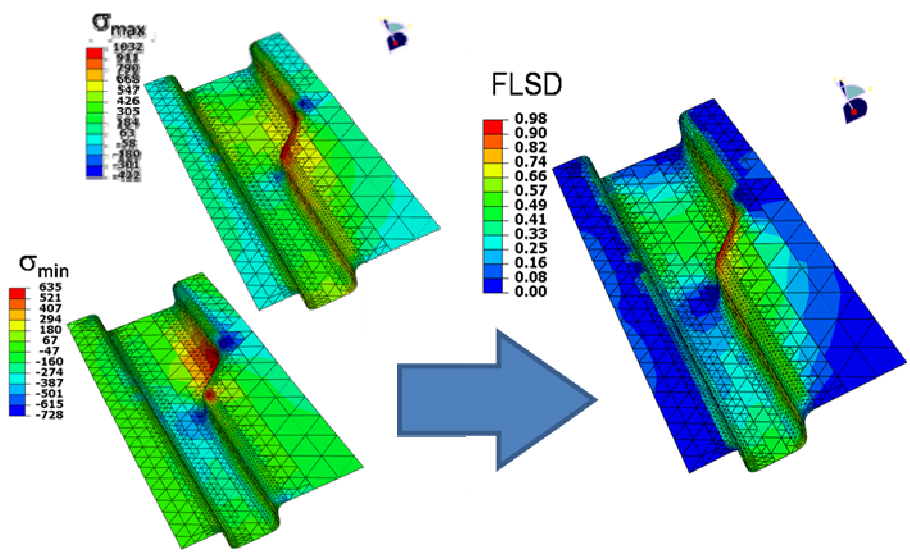

Figure 12. Maximum and minimum stresses from AUTOFORM and the resulting FLSD criterion values as seen in Abaqus/viewer. In this case the material is DP780

4. Real forming and validation

Actual specimens were drawn and maximum drawing depth was determined for each material. The DP780, DOCOL1200 and DOCOL1500 steels reach 23mm, 12,4mm and 11.5mm respectively. Examples of the drawn specimens are shown in Figure 13.

A summarizing graph comparing experimental and simulated results is shown in Figure 14.

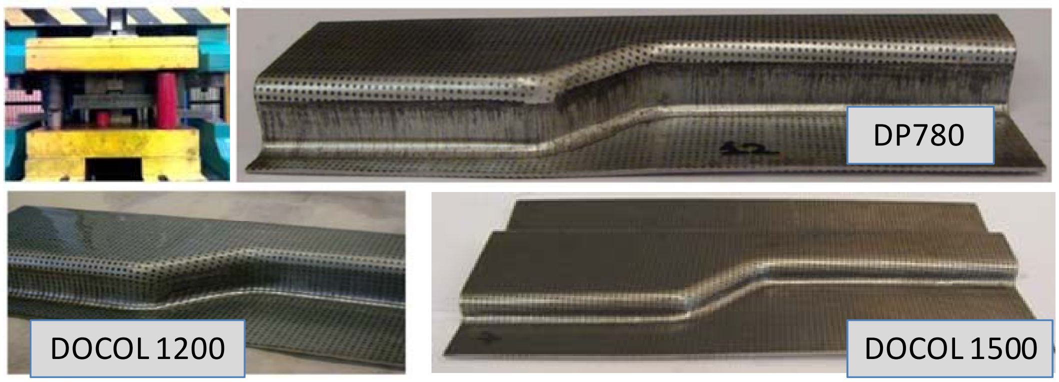

Figure 13. Examples of drawn specimens for the 3 materials unders study.

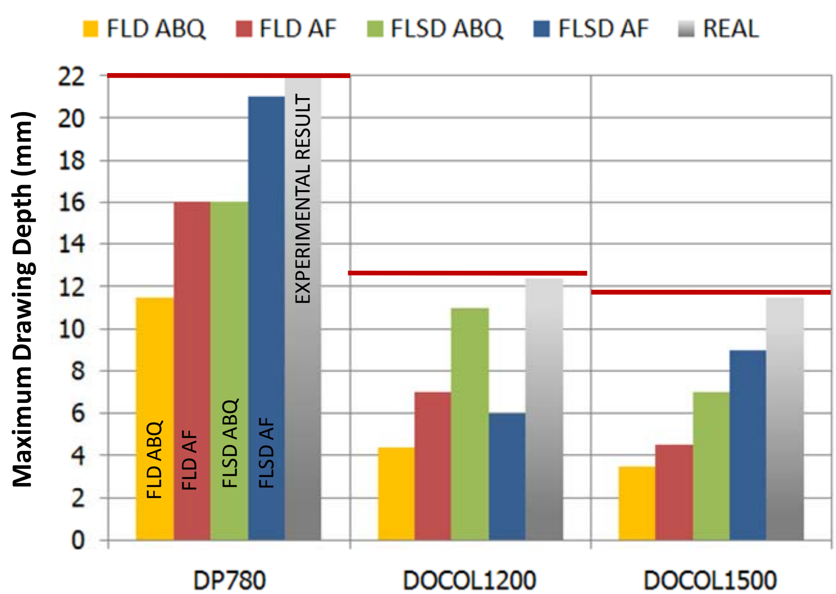

Figure 14. Summary graph comparing experimental and simulated results for the different materials and failure criteria.

5. Conclusion

A methodology that allows determining FLSD curves has been presented. Different simulations and failure criteria have been compared. Some trends that are common to the three studied materials are:

- Parts always fail at depths higher than predicted through simulation,
- FLD predicts an earlier failure,
- AUTOFORM predicts higher drawability than Abaqus,

Only the simulation of DOCOL 1200 with AUTOFORM breaks these trends.

These results indicate that the FLSD is a good failure prediction tool for drawn parts. However, these conclusions should be tested with more complex geometries and deformation paths.

The differences between results from different solvers must be studied as well. The issue of whether this differences are a consequence of the algorithms in use or due to how the solver processes the mechanical behavior curves needs to be addressed.

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